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TECHNI-RHO PRODUCTION AT SSC AND LHC*

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ABSTRACT

We use a parton-level Monte Carlo to assess the reach of the SSC and LHC for discovering a techni-rho through its purely leptonic decay channels. We find the techni-rho couplings using the familiar techniques of nonlinear realizations. We compute the signal and background for techni-rhos of arbitrary mass and width, restricted only by requirements of partial-wave unitarity.

I. INTRODUCTION

A major goal of the SSC is to find the mechanism responsible for the weak-interaction symmetry breaking. Of the various possibilities, a perennial favorite is technicolor [1], where a new set of strong interactions breaks the chiral symmetries associated with techni-quarks, just as ordinary QCD breaks the chiral symmetries associated with ordinary quarks.

In analogy to QCD, the technicolor spectrum contains Goldstone bosons, techni-mesons and techni-baryons. Three of the Goldstone particles become the longitudinal components of the W and the Z. The remaining Goldstone particles acquire mass because the full chiral symmetry group is broken by gauge and so-called "extended" technicolor interactions. The numbers and masses of these "pseudo" Goldstone bosons are very model-dependent; they follow from the precise pattern of chiral symmetry breaking [2]. In contrast, the properties of the techni-mesons and techni-baryons are much less model dependent. They are the particles that must be found if technicolor is indeed correct.

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Most of the phenomenology associated with technicolor theories has been carried out under the assumption that the new strong dynamics is described by an SU(N) gauge theory. This allows one to use large N arguments to predict the masses and the widths of the techni-mesons and the techni-baryons [3]. For example, the analog of the rho, called the techni-rho, is assumed to have mass

$$M_\rho \;=\; \sqrt{\frac{3}{N}}\,\frac{v}{f_\pi}\;\;770\ \mathrm{GeV} \qquad (1)$$

and width

$$\Gamma_\rho \;=\; \left(\frac{3}{N}\right)^{\frac{3}{2}}\;\frac{v}{f_\pi}\;\;150\ \mathrm{GeV}\;. \qquad (2)$$

Although technicolor is a beautiful idea, the simplest versions of technicolor theories do not work. They have many problems, generally associated with the "extended" technicolor sector that communicates the chiral symmetry breaking to the ordinary quarks and leptons. The simplest technicolor theories are afflicted by one or more of the following problems:

1) The ordinary quark masses are too small;

2) The pseudo Goldstone bosons are too light; or

3) The flavor-changing neutral currents are too large.

These problems have led in recent years to the introduction of "walking" technicolor theories [4], where the strong dynamics are not of QCD-type. Walking technicolor theories have their own problems [5], but they represent an important next step towards phenomenologically-viable technicolor theories.

The problem with analyzing technicolor phenomenology at the SSC is that there is no Standard Model of Technicolor. No known model is in accord with all experiments. However, the aesthetic appeal of technicolor is so strong that it is worthwhile to search for technicolor signals, even in the absence of a completely consistent model [6,7].

In this paper we will pursue such a model-independent analysis. We will focus our attention on what we consider to be the most generic signature of technicolor, the existence of a techni-rho, a spin-one, isospin-one resonance of unknown mass and width. We will use a parton-level Monte Carlo to compare signal to background for the purely leptonic decays of such a particle. In this way we will assess the reach of the SSC and LHC, as a function of the techni-rho mass and width [8].

II. THE SIGNAL

2.1 The Lagrangian

Almost by definition, any successful technicolor theory must contain at least three techni-pions, the Goldstone bosons that become the longitudinal components of the W and the Z. In technicolor theories, these techni-pions arise from the breaking of a global chiral symmetry group G down to some subgroup H. Given the groups G and H, the interactions of the Goldstone particles are completely determined by the chiral symmetry [9].

In what follows, we will assume that there are just three techni-pions. This assumption eliminates many of the model-dependent questions associated with the pseudo Goldstone spectrum. Of course, the analysis presented here can easily be extended to include such particles when a realistic technicolor model is at hand.

Once we have made this assumption, it is not hard to show that the allowed chiral symmetry groups are either [10]

1) $G = \mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$; $H = \mathrm{SU}(2)_V$, or

2) $G = \mathrm{SU}(2)_L \times U(1)$; $H = U(1)$.

The second choice is ruled out by measurements of the rho parameter, $\rho = M_W/M_Z \cos\theta \simeq 1$. In contrast, the first possibility automatically ensures that $\rho \simeq 1$. This is because the unbroken $\mathrm{SU}(2)_V$ guarantees that the Goldstone bosons transform as a triplet of "weak isospin."

The fact that $G = \mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ and $H = \mathrm{SU}(2)_V$ completely determines the low-energy interactions of the techni-pions. It also determines the coupling of the techni-rho. The coupling of the techni-rho to the techni-pions must not only preserve weak isospin; it must also preserve the full chiral symmetry group G.

To find the techni-rho couplings, we shall use the techniques of nonlinear realizations, pioneered by Weinberg [11] and by Callan, Coleman, Wess and Zumino [9]. These techniques give the most general techni-rho coupling consistent with chiral symmetry. They give rise to a nonlinear effective Lagrangian that describes techni-rho dynamics up to a scale of about $\hat{s} \simeq 16\pi^2 v^2$, or $E \simeq 3$ TeV.

Following this method, we start by parametrizing the three techni-pions w^a in terms of the SU(2) group element

$$\xi \;=\; \exp(iw^a T^a/v) \;, \tag{3}$$

where v is the weak decay constant, about 246 GeV, and the T^a are three hermitian generators of SU(2), normalized so that $\mathrm{Tr}\, T^a T^b = \frac{1}{2}\delta^{ab}$. We then represent an $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$ transformation on ξ as follows:

$$\xi \;\to\; \xi' \;\equiv\; L\xi U^\dagger \;=\; U\xi R^\dagger \;. \tag{4}$$

Here L, R and U are SU(2) group elements; and U is a (nonlinear) function of L, R and w^a, chosen to restore ξ' to the form (3). Note that when $L = R$, $U = L = R$, and the transformation linearizes. This simply says that the w^a transform as a triplet of weak isospin.

Given these transformations, we can construct the following currents,

$$\begin{aligned} J_L \;&=\; \xi^\dagger\partial\xi \;\;\to\; UJ_LU^\dagger \;+\; U\partial U^\dagger \\ J_R \;&=\; \xi\partial\xi^\dagger \;\;\to\; UJ_RU^\dagger \;+\; U\partial U^\dagger \;. \end{aligned} \tag{5}$$

The currents J_L and J_R transform as gauge fields under $\mathrm{SU}(2)_V$ transformations. As above, note that these transformations linearize when $L = R = U$.

The transformations (5) inspire us to choose the techni-rho transformation in exactly the same way,

$$V \;\to\; UVU^\dagger \;+\; ig''^{-1}\, U\partial U^\dagger \;, \tag{6}$$

where $V = V^aT^a$, and g'' is the techni-rho coupling constant. When $L = R = U$, equation (6) implies that the techni-rho transforms as an isotriplet of weak isospin.

Given these transformations, it is easy to construct the most general Lagrangian consistent with chiral symmetry. We first write down the currents

$$\begin{aligned} \mathcal{A} \;&=\; J_L \;-\; J_R \\ \mathcal{V} \;&=\; J_L \;+\; J_R \;+\; 2ig''V \;, \end{aligned} \tag{7}$$

which transform as follows under an arbitrary chiral transformation,

$$\begin{aligned} \mathcal{A} &\rightarrow U \mathcal{A} U^{\dagger} \\ \mathcal{V} &\rightarrow U \mathcal{V} U^{\dagger} \, . \end{aligned} \tag{8}$$

Under parity (which exchanges J_L with J_R and leaves V invariant), $\mathcal{V}$ is invariant, while $\mathcal{A}$ changes sign. If we impose the additional assumption that the technicolor dynamics conserve parity, we are led immediately to the following interaction Lagrangian,

$$\mathcal{L} \;=\; -\,\frac{1}{4}\,v^2\,\mathrm{Tr}\,\mathcal{A}_\mu \mathcal{A}_\mu \;-\; \frac{1}{4}\,a v^2\,\mathrm{Tr}\,\mathcal{V}_\mu \mathcal{V}_\mu \;+\; \ldots . \tag{9}$$

The dots denote possible terms with more derivatives, which give the subleading behavior in the energy expansion. Up to possible field redefinitions, this is the most general interaction consistent with chiral symmetry [12].

Of course, to connect the techni-rho dynamics to the standard model, we must add fermions as well as the electroweak gauge bosons. The electroweak gauge bosons are added by gauging $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$. For the case at hand, $\mathrm{U}(1)_Y = T_R^3 + \mathrm{U}(1)_{B-L}$, where T_R^3 is a generator of $\mathrm{SU}(2)_R$, and $\mathrm{U}(1)_{B-L}$ is proportional to baryon minus lepton number. As usual, the electroweak gauge bosons are chosen to transform as follows,

$$\begin{aligned} W &= W^a T_L^a &&\rightarrow\; L W L^{\dagger} \;+\; i g^{-1}\, L \partial L^{\dagger} \\ B &= B T_R^3 &&\rightarrow\; B \;+\; i g'^{-1}\, R \partial R^{\dagger} \, . \end{aligned} \tag{10}$$

With this choice, the currents J_L and J_R become

$$\begin{aligned} \tilde{J}_L &= \xi^{\dagger}\,(\partial - igW)\,\xi \\ \tilde{J}_R &= \xi\,(\partial - ig'B)\,\xi^{\dagger} \, . \end{aligned} \tag{11}$$

The gauge-covariant currents are then

$$\begin{aligned} \tilde{\mathcal{A}} &= \tilde{J}_L \;-\; \tilde{J}_R \\ \tilde{\mathcal{V}} &= \tilde{J}_L \;+\; \tilde{J}_R \;+\; 2ig''V \, , \end{aligned} \tag{12}$$

and the interaction Lagrangian is simply

$$\mathcal{L} \;=\; -\,\frac{1}{4}\,v^2\,\mathrm{Tr}\,\tilde{\mathcal{A}}_\mu \tilde{\mathcal{A}}_\mu \;-\; \frac{1}{4}\,a v^2\,\mathrm{Tr}\,\tilde{\mathcal{V}}_\mu \tilde{\mathcal{V}}_\mu \;+\; \ldots . \tag{13}$$

The Lagrangian $\mathcal{L}$ is locally $\mathrm{SU}(2)_L \times \mathrm{U}(1)_Y$ invariant; it is also chirally invariant up to terms proportional to the hypercharge coupling g'.

The couplings to the fermions are also determined by the formalism of nonlinear realizations. For simplicity, let us assume that we have only one family of left-handed quarks ψ_L, and one family of right-handed quarks ψ_R, which transform as follows under $\mathrm{SU}(2)_L \times \mathrm{SU}(2)_R$,

$$\begin{aligned} \psi_L &\rightarrow L\,\psi_L \\ \psi_R &\rightarrow R\,\psi_R \, . \end{aligned} \tag{14}$$

The general chirally-invariant kinetic term is just as in the standard model. Now, however, there are additional couplings, such as

$$\begin{aligned} \mathcal{L} \;=\; & b\,[\bar{\psi}_L \xi\, \gamma^\mu\,(\tilde{\mathcal{V}}_\mu + \tilde{\mathcal{A}}_\mu)\,\xi^{\dagger} \psi_L \\ & +\, \bar{\psi}_R \xi^{\dagger}\, \gamma^\mu\,(\tilde{\mathcal{V}}_\mu - \tilde{\mathcal{A}}_\mu)\,\xi \psi_R] \, , \end{aligned} \tag{15}$$

which, for the sake of argument, we have taken to be parity-invariant. In technicolor theories, such interactions are induced by the "extended" technicolor sector. For the purposes of this paper, however, we will ignore these couplings by setting $b = 0$. We do this because of the great uncertainty about the "extended" sector in most technicolor theories. This is a conservative assumption; taking $b \neq 0$ can only improve the signal.

It is now straightforward to analyze the physics of the techni-rho system. In the limit $M_\rho >> M_W$, M_Z, the low-energy spectrum is exactly as in the standard model,

$$\begin{aligned} M_W^2 &= \frac{1}{4}\,g^2 v^2 \\ M_Z^2 &= \frac{1}{4}\,(g^2 + g'^2)\,v^2 \;\equiv\; M_W^2\,\cos^{-2}\theta \, , \end{aligned} \tag{16}$$

up to corrections of order g/g'' [13]. There is also a mixing between the techni-rho and the W^a of strength $g/2g''$. This mixing induces a weak coupling of the techni-rho to fermions, even when $b = 0$.

The parameters g, g', and v are fixed by the physics of the W and Z. The parameters g'' and a, however, are free. One combination is fixed by the mass of the techni-rho,

$$M_\rho^2 \;=\; a g''^2 v^2 \, , \tag{17}$$

and another by its width into techni-pions,

$$\Gamma_\rho \;=\; \frac{a M_\rho^3}{192 \pi v^2} \, . \tag{18}$$

Because of the chiral symmetry, these two parameters completely determine the theory.

2.2 The Results

We are now ready to compute the techni-rho signal at the SSC. For practical purposes, the techni-rho is just an isospin-one spin-one resonance which decays into pairs of the three techni-pions. At SSC energies,

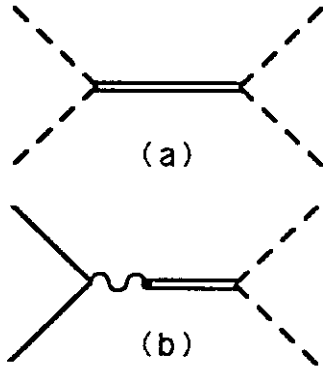

Fig. 1. Techni-rho production via (a) $W_L W_L$ fusion, and (b) the Drell-Yan mechanism.

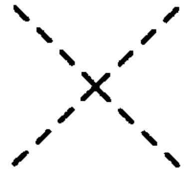

Fig. 2. Continuum $W_L W_L$ scattering required by chiral symmetry.

the techni-pions are effectively longitudinal W's and Z's. This can be made rigorous by invoking the weak-interaction equivalence theorem, which holds to all orders in the energy expansion $\hat{s}/16\pi^2 v^2$ [14].

In an attempt to beat the backgrounds, we shall focus our attention on the leptonic decays of the final state particles. Since the techni-rho is an isospin-one spin-one resonance, it should decay primarily to the W^+W^- and $W^\pm Z$ final states. The W^+W^- channel is very difficult to detect. Not only are the two W's impossible to reconstruct through their leptonic decays, but the background from $t\bar{t}$ pairs must also be eliminated. The $W^\pm Z$ channel is easier because one can reconstruct the final-state Z. Therefore we shall focus our attention on this channel [15].

The dominant techni-rho production comes from two diagrams, shown in Figure 1 [16]. The first is $W_L W_L$ fusion into a techni-rho, and the other is a Drell-Yan process, with the techni-rho mixing with a transverse W. At SSC energies, there are potentially significant contributions from $W_T W_T$ fusion as well. We have ignored this production mechanism because of the uncertainties associated with the W_T luminosities in the effective W approximation [17,18].

A third important diagram is shown in Figure 2. This diagram gives a continuum "background" to the signal; it is required by the chiral symmetry of the Lagrangian. There are other continuum diagrams that involve transverse W's, but we will ignore them because they are suppressed by powers of g. We have included the diagrams of Figures 1 and 2 in our signal computations; the diagram of Figure 2 contributes to the signal away from the techni-rho resonance.

It is straightforward to compute all three diagrams in terms of M_ρ and Γ_ρ. Because of the chiral symmetry, these two parameters completely characterize the signal. However, not all values of these parameters give a consistent theory. The problem is that the resulting subprocesses can violate unitarity.

There are no unitarity problems with the amplitudes involving fermions or transverse vector bosons because all these amplitudes are weakly coupled. The amplitudes to watch are those that involve the longitudinal vector bosons, which couple strongly to the techni-rho, as well as to each other.

Therefore, to check unitarity, we focus our attention on the diagrams of Figures 1a and 2. We first write the resulting amplitudes in terms of spin-isospin partial waves. As expected, only two partial waves contribute to the process of interest: the isospin-one, spin-one partial wave T_{11}, and the isospin-two, spin-zero partial wave T_{20}. We ensure the unitarity of the T_{11} wave by including the width in the propagators of Figure 1. This, however, does not unitarize the T_{20} partial wave. Therefore we will use this partial wave to restrict the allowed values of M_ρ and Γ_ρ. Imposing the condition Re $T_{20} < 1/2$ for energies up to $1.5\, M_\rho$, we find that M_ρ and Γ_ρ are restricted to the region shown in Figure 3. In this figure, the KSFR width [19] is drawn with a dashed line. (The KSFR width corresponds to $a = 2$. It is close to the width assumed for SU(N) technicolor theories.) We see that the KSFR width is near the minimum allowed value [20,21].

In what follows we analyze the signal from six pos-

Table I
Techni-rho Masses and Widths, in GeV.

Mass	1000	1500	2000
Narrow width	55	185	440
Broad width	200	400	800

Table II
Signal Cross Sections, in Events per SSC-year

Mass	Width	Drell-Yan	WZ Fusion	Total
1000	55	178	39	217
1000	200	58	124	182
1500	185	29	18	47
1500	400	15	31	46
2000	440	6.9	9.0	16
2000	800	3.9	12	16

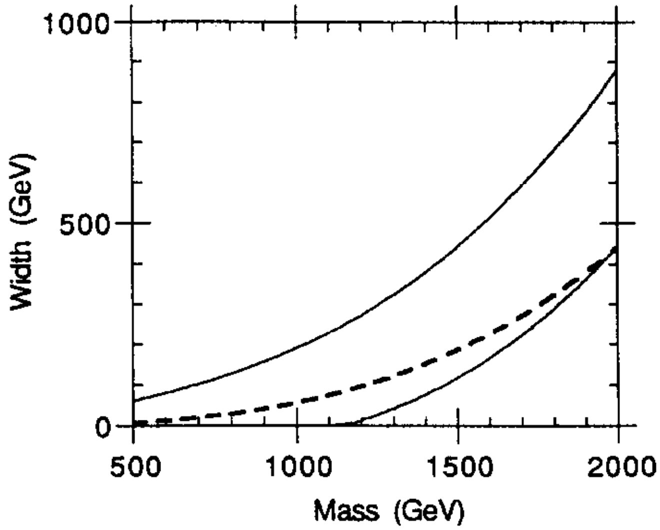

Fig. 3. Masses and widths allowed by unitarity of the T_{20} partial wave. The dashed line denotes the KSFR value of the width.

sible techni-rhos, consistent with the unitarity limits. We choose a narrow rho and a broad rho. For the narrow rho, we take the width to be given by its KSFR value. For the broad rho, we use the maximum value allowed on the unitarity diagram. Thus we consider the masses and widths shown in Table I, where all masses and widths are in GeV. The parameters presented in the table lie within the domain of validity of the effective field theory.

We have examined the signal for each techni-rho using a parton-level Monte Carlo. We looked at the decay into $W^{\pm}Z$, with subsequent decay into electrons and muons (for the SSC) or muons (for LHC). The vector boson decays are performed isotropically in phase space. Imposing an acceptance cut on the leptons,

1) $p_T(\ell^{\pm}) > 20$ GeV,

2) $|y(\ell^{\pm})| < 2.5$,

we found total integrated signals (for the SSC), as shown in Table II [22]. In the table, all cross-sections are quoted in events per SSC-year, before efficiencies are taken into account, assuming $\sqrt{s} = 40$ TeV and an annual luminosity of 10 fb^{-1}. These numbers were found using the EHLQ set I structure functions for the quark distributions, evaluated at a scale $Q^2 = \hat{s}$. The W_L luminosities were found using the effective W approximation [17].

Note that the fusion diagram becomes more important as the techni-rho width-to-mass ratio is increased. This simply reflects the fact that the techni-rho technipion coupling scales as $(\Gamma_\rho/M_\rho)^{\frac{1}{2}}$.

III. THE BACKGROUNDS

The signals quoted above are not of much help without a careful assessment of the background. The major source of background is from the standard $q\bar{q}$ subprocess [6,23], $q\bar{q} \to W^{\pm}Z$. However, at SSC energies, transverse vector scattering is important as well [21]. Therefore we have also included the transverse backgrounds $W_T^{\pm}Z_T \to W_T^{\pm}Z_T$ and $W_T^{\pm}\gamma \to W_T^{\pm}Z_T$. In computing the backgrounds, we have not included any diagrams with longitudinal vectors in the initial or final states. Since we are studying a technicolor theory, we have also excluded all diagrams with Higgs exchanges.

To compute the backgrounds, we have used the EHLQ set I structure functions for the quarks, evaluated at $Q^2 = \hat{s}$. We have also used the effective W approximation for the transverse gauge particles, evaluated at the same scale. For transverse gauge bosons, this approximation suffers from a fairly large uncertainty because of the unknown scale dependence. The scale we have chosen tends to overestimate the W_TZ_T backgrounds. Choosing $Q^2 = M^2_{WZ}$ would reduce the W_TZ_T background by a factor of five, and the $W_T\gamma$

Table III
Background Cross Sections, in Events per SSC-year

$q\bar{q}$	$W_T^{\pm}Z_T$	$W^{\pm}\gamma$
2,900	1,400	1,000

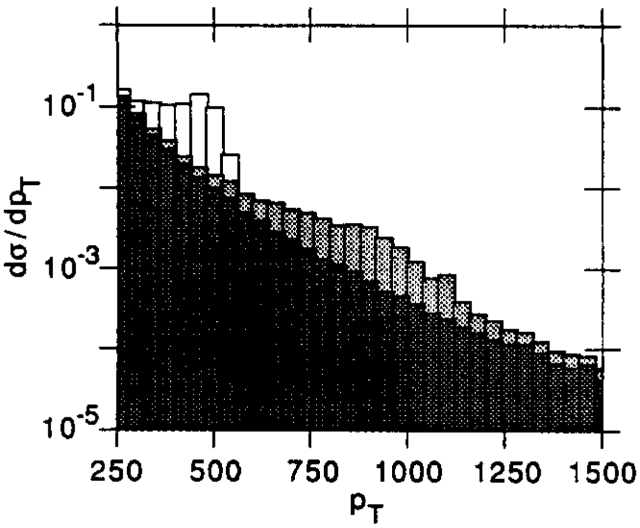

Fig. 4. The transverse momentum of the reconstructed Z, for the background and for the one and two TeV narrow-width techni-rhos of Table I, in fb/GeV.

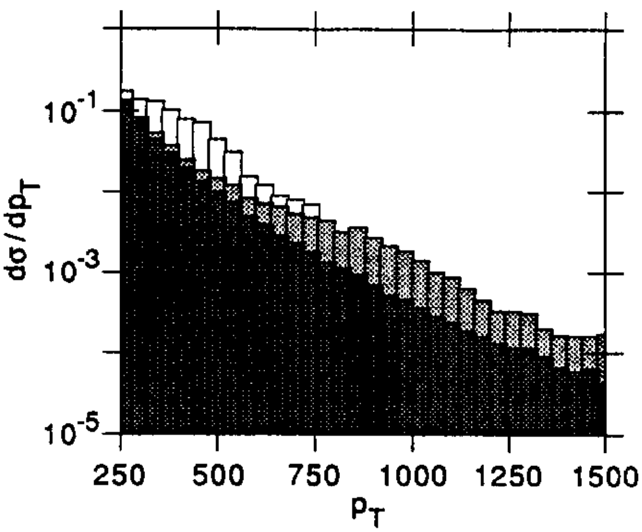

Fig. 5. The transverse momentum of the reconstructed Z, for the background and for the one and two TeV broad-width techni-rhos of Table I, in fb/GeV.

background by a factor of two. Because of this, our results for the signal/background ratio are conservative.

We evaluated the backgrounds using the same acceptance cuts as for the signals, and found the total cross sections given in Table III. As above, the cross-sections are given in units of events/SSC-year. In absolute magnitude, the background clearly dwarfs the signal.

IV. DISCUSSION

From the above numbers, we see that the total background is large. Fortunately, it is possible to extract a signal because of the resonance structure of the techni-rho. This can be seen from Figures 4 and 5, where we plot the p_T spectra of the reconstructed Z. We show the contributions from the background, and from the signal plus background, for each of the six rhos. In each case the Jacobian peak is visible above the background at $p_T = M_\rho/2$ (except possibly for the broad 2 TeV rho).

Using this information, it is possible to further suppress the background by imposing a more stringent cut on the p_T of the reconstructed Z: $p_T(Z) > M_\rho/4$. With this cut, the techni-rho would be expected to show up cleanly in the WZ invariant mass spectrum. However, because of the missing neutrino, it is perhaps better to look at the so-called cluster transverse mass [24], defined as

$$M_T \;=\; \left(|\vec{p}_{T\ell\bar{\ell}\ell}|^2 + m^2_{\ell\bar{\ell}\ell}\right)^{\frac{1}{2}} \;+\; |\,\not{p}_T\,| \qquad (19)$$

With the lepton acceptance cut and the more stringent $p_T(Z)$ cut, the M_T distributions are shown in Figures 6 and 7. Once again, we see pronounced peaks at the techni-rho mass. Integrating over the peaks, we find the expected number of events per SSC year, as shown in Table IV.

From the table we see that the signal always predominates over background, but the total event rate is small for a heavy techni-rho. The event rate would be helped if there were a direct coupling of the techni-rho to the quarks, with $b \neq 0$, but this is not a necessary feature of technicolor. The numbers in Table IV indicate that serious consideration should be given to a high-luminosity upgrade for the SSC.

For comparison, we include the results for the LHC in Table V. The numbers in the table include the muonic decays only, and assume $\sqrt{s} = 16$ TeV with an annual luminosity of 500 fb^{-1}. As is evident from

Table IV
Signal and Background Cross Sections, in Events per SSC-year

Mass	Width	Interval	Signal	Bkgd	S/B
1000	55	780 - 1200	185	47	3.9
1000	200	780 - 1200	136	47	2.9
1500	185	1200 - 1680	31	10	3.1
1500	400	1200 - 1680	25	10	2.5
2000	440	1620 - 2400	8.5	3.9	2.2
2000	800	1620 - 2400	8.4	3.9	2.1

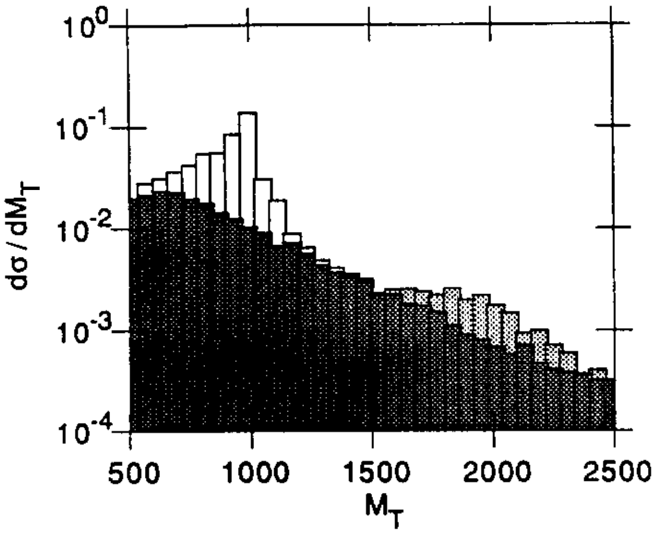

Fig. 6. The cluster transverse mass of the charged leptons, for the background (with $p_T(Z) > 250$ GeV) and for the one and two TeV narrow-width techni-rhos of Table I, in fb/GeV.

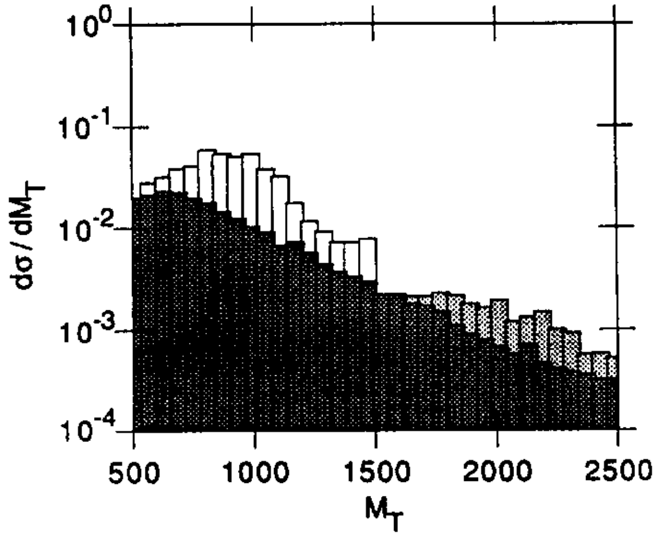

Fig. 7. The cluster transverse mass of the charged leptons, for the background (with $p_T(Z) > 250$ GeV) and for the one and two TeV broad-width techni-rhos of Table I, in fb/GeV.

the table, the LHC does not have the reach to separate signal from background for the heavier techni-rhos.

We shall conclude by discussing the possibility of using the semi-leptonic channels to detect the resonance. Clearly, the most useful channel would be $Z \to \ell^+\ell^-$; $W^\pm \to jj$. Because of the larger branching ratio for hadronic W decay, we would expect the signal to be enhanced by a factor of three relative to the purely leptonic modes, modulo the jet acceptance.

However, besides the irreducible electroweak backgrounds, there are now new backgrounds from QCD processes, such as Z plus two jets. Imposing the lepton acceptance cuts as above, and requiring that the two QCD jets obey $p_T(j) > 50$ GeV, $|y(j)| < 3$ and $\Delta R_{jj} > 0.7$ to specify the jet-jet separation, we find the cross section for $Z(\to e^+e^-) + 2$ jets to be about 115 pb – more than two orders of magnitude larger than the signal from a 500 GeV rho. If we

Table V
Signal and Background Cross Sections, in Events per LHC-year

Mass	Width	Interval	Signal	Bkgd	S/B
1000	55	800 – 1200	484	112	4.3
1000	200	800 – 1200	259	112	2.3
1500	185	1200 – 1800	50	20	2.5
1500	400	1200 – 1800	33	20	1.6
2000	440	1500 – 2500	10	7.3	1.4
2000	800	1500 – 2500	7.8	7.3	1.1

further require $M_{jj} = M_W \pm 10$ GeV, together with $p_T(Z) > M_\rho/4$, the QCD background is still about four times larger than the signal for $M_\rho = 500$ GeV. It completely masks the peak.

Of course, such a $p_T(Z)$ cut would be of more help for a heavier techni-rho, but it is still not sufficient to isolate the signal. The problem is that the final-state W's are so energetic that their decay products coalesce into a single jet. In this case, the single-jet QCD process $Z +$jet will be the major background. The rate for this process is huge, of order 350 pb. A detailed Monte Carlo, including hadronization, is necessary to determine the feasibility of using this semi-leptonic mode of techni-rho decay. It looks like this decay channel is less promising than the purely leptonic mode.

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